

East Baltic Region

D. Kaljo, H. Nestor and L. Põlma†

Institute of Geology, Estonian Academy of Sciences, Estonia Puistee 7, Tallinn 200101, USSR

† L. Põlma died in January 1988.

Synopsis

Five confacies belts from north to south, from Estonia through Latvia to Lithuania, are described briefly through the late Ordovician and early Silurian, with their varied facies and faunas. Despite clear breaks corresponding to the Ordovician–Silurian boundary at the edges of the depositional basin, rocks of Hirnantian age are identified from the centre of the basin, including *Hirnantia* and *Dalmanitina* faunas in the Porkuni Regional Stage and basal Silurian faunas, including some graptolites, chitinozoans, brachiopods and conodonts, from the overlying Juuru Regional Stage. Any stratigraphical break at the boundary appears to be represented by no more than a facies change.

Introduction

The East Baltic area is a part of the extensive gulf-like Baltic sedimentary basin (Männil 1966; Kaljo & Jürgenson 1977). The uppermost Ordovician and the lowermost Silurian are mostly represented by carbonate or terrigenous-carbonate rocks with an exceptionally rich benthic shelly fauna; however, pelagic groups of fossils, especially graptolites, are of a more restricted distribution. The rocks are tectonically undisturbed, and unmetamorphosed (CAI 1–1.5), with only a little dolomitization in places, and the fossils are well preserved. The bedding is almost horizontal and dips slightly to the centre of the basin. The distribution of the Ashgill–Llandovery rocks in the East Baltic is shown in Fig. 1. The outer margin of the area is erosional and corresponds to the base of the Ashgill (Vormsi Regional Stage). The axial part of the basin with the most deep-water rocks corresponds to the Baltic Syncline (IV belt), and along its margins there occur shallower-water sediments.

Most of the area is covered by younger rocks. The outcrops of the Ordovician–Silurian boundary strata are confined to North Estonia (Belt I in Fig. 1), where only comparatively shallow-water deposits are exposed. A more complete succession of facies in the basin can be seen in borehole sections. Fig. 2 presents a cross section of Ashgill and Lower and Middle Llandovery strata along the Orjaku–Remte–Ukmerge line, which is shown in Fig. 1. The section goes across the main facies belts of the basin and shows the relations between local lithostratigraphical units and their general lithology. In the figure stratigraphical units are marked with letter-indexes: their full nomenclature is given in Fig. 3.

Confacies belts

In the East Baltic five confacies belts can be distinguished in Ordovician–Silurian boundary beds. Their distribution is shown in Fig. 1 and their lithological composition in Fig. 2.

Type I—the most shallow-water sections in North Estonia and Hiiumaa Island represented by aphanitic, bioclastic and biohermal limestones. In the Raikküla Formation there occur primary argillaceous dolomites of lagoonal origin in places. Some considerable stratigraphical gaps have been established (Fig. 3). The Ordovician ends with Early Porkuni bioclastic, biohermal and arenaceous limestones (Ärina Formation), which carry a *Streptis* brachiopod community (Hints 1986), disconformably overlain by Juuru aphanitic (Koigi Member) and biomicritic limestones (Varbola Formation) with a *Stricklandia* community (Rubel 1970).

Type II—sections in central Estonia and Saaremaa Island. Represented by marls, aphanitic and biomicritic nodular limestones. The sections are more complete than in Type I. A distinct hiatus has been established only in the upper part of the Porkuni Regional Stage and in the west at the top of the Raikküla Stage. The Ordovician–Silurian boundary interval is similar to the sections of Type I, but southwards the Ärina Formation and the Koigi Member thin out

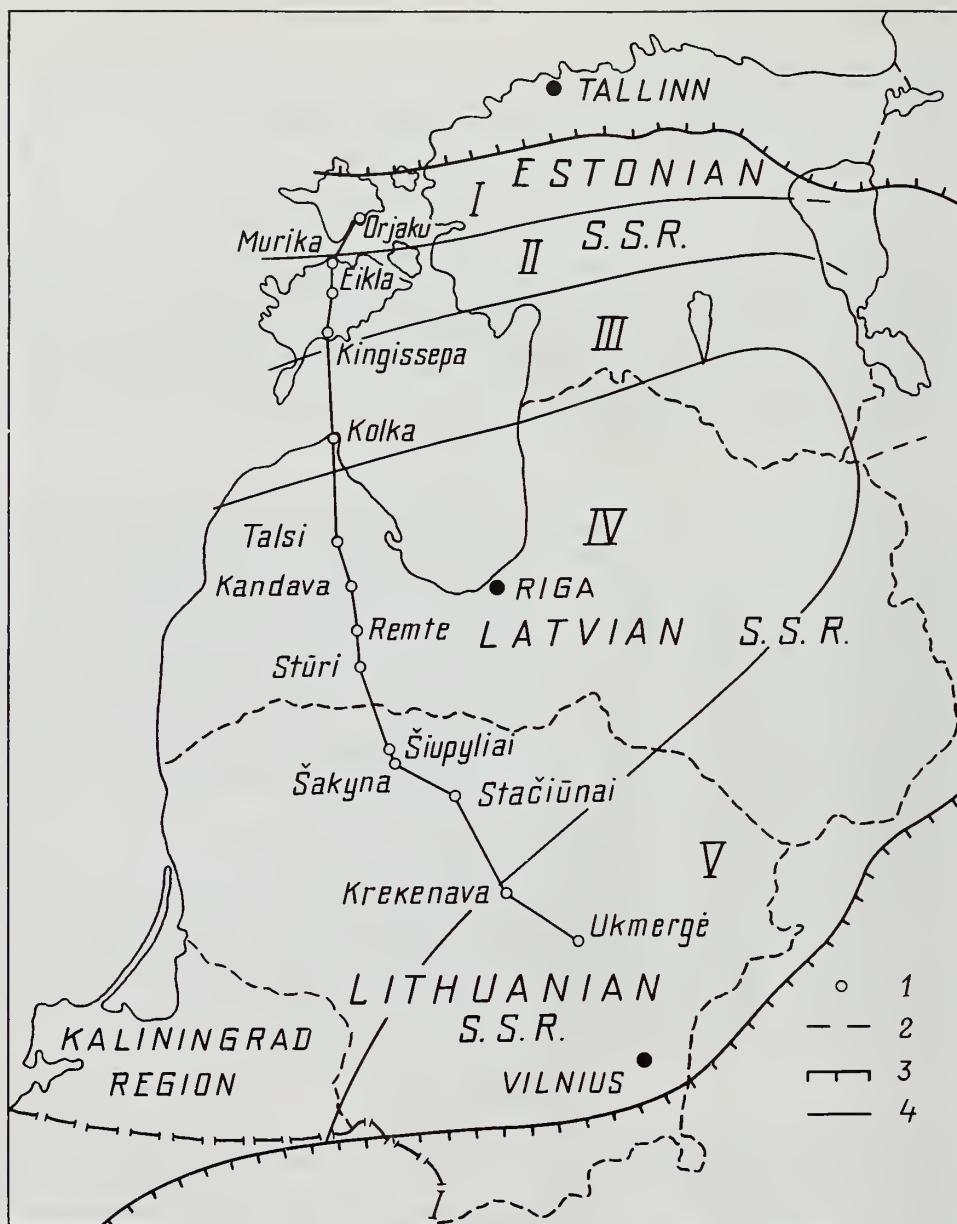


Fig. 1 Distribution of Ordovician-Silurian boundary rocks in the East Baltic area. 1—boreholes, 2—administrative boundaries, 3—outer margin of the distribution of Ashgill and Llandovery rocks, 4—boundaries of main types of sections, marked with Roman numbers.

and the boundary of the systems continues in a comparatively monotonous complex of nodular limestones and marls. In places the Porkuni Regional Stage may be missing.

Type III—sections in south Estonia and north-west Latvia. Marls and argillaceous limestones, including their red-coloured varieties, are significant lithologies. In the Llandovery, aphanitic limestones alternate with marls. A considerable erosional gap corresponds to the upper part of the Pirgu Regional Stage, and this gap increases westwards. The uppermost

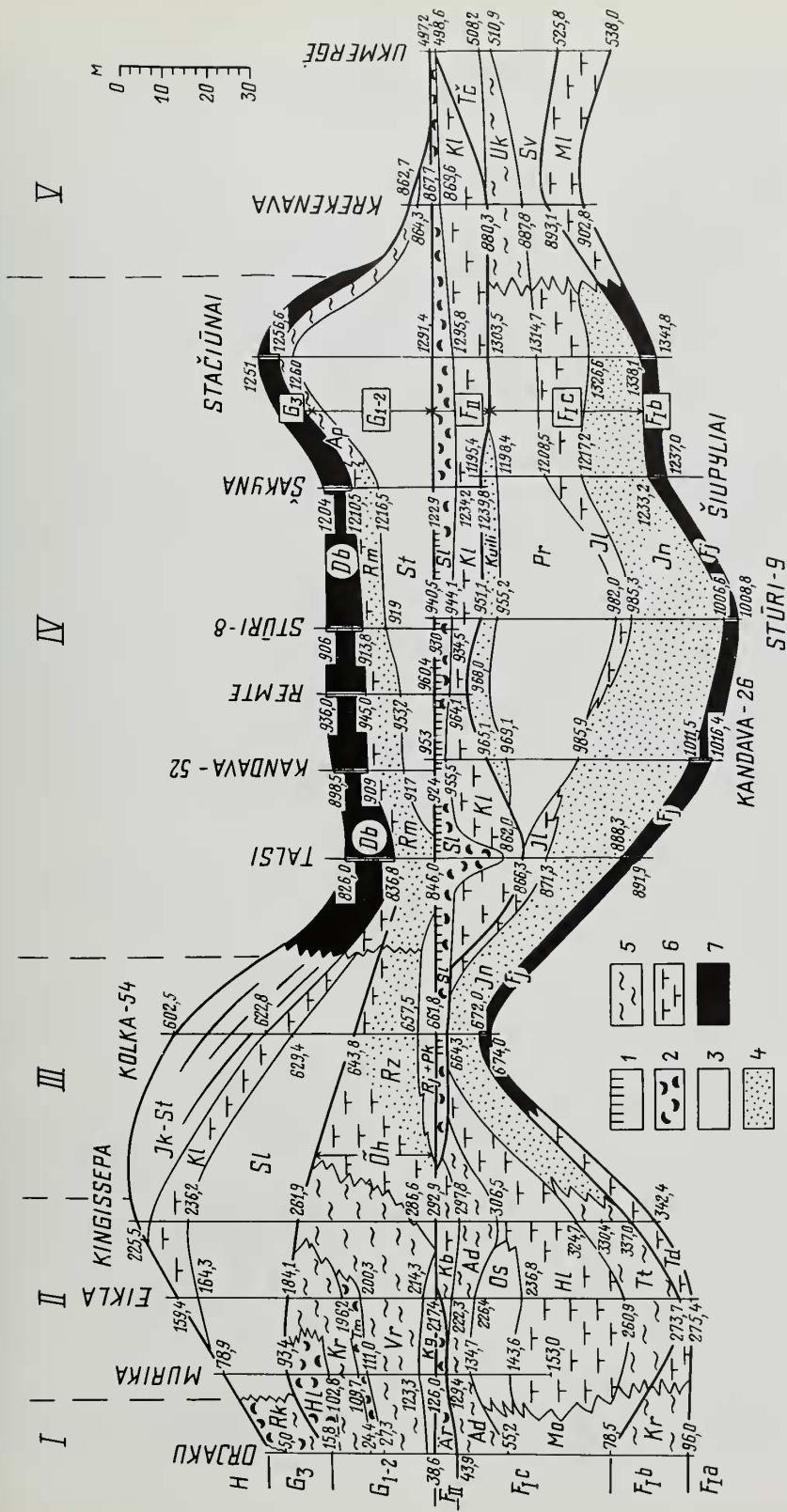


Fig. 2. Stratigraphical cross section of the boundary interval along the line shown in Fig. 1—thin-bedded argillaceous-carbonate rocks of lagoonal origin; 2—biopartic, clastic and oolitic limestones (sparitic calcarenites); 3—fine- to cryptocrystalline limestones (calclutites); 4—red argillaceous limestones and marls; 5—biomicritic nodular limestones and marls; 6—grey argillaceous limestones and marls; 7—graptolitic mudstones (shales). For meaning of the stratigraphical indexes see Fig. 3; the index of a formation consists of the first letter and the following first consonant (if any) of the name.

Ordovician is represented by marls and argillaceous limestones with the *Dalmanitina* Fauna (Kuldiga Formation). Above this occur biosparitic, oolitic and arenaceous limestones of the Saldus Formation. The Silurian begins with marls and argillaceous limestones of the Õhne Formation with the *Clorinda* community (Rubel 1970).

Type IV—sections in southeast Estonia, considerable part of Latvia, west Lithuania and the Kaliningrad Region. The studied stratigraphical interval begins and ends with dark graptolitic mudstones with the assemblage of the *Pleurograptus linearis* Zone in the Ordovician part (Fjäck Formation) and of the *Coronograptus cyphus*–*Monograptus sedgwickii* Zones in the Silurian (Dobele Formation). Between these key beds there occur red and grey calcareous mudstones, marls and aphanitic limestones. The uppermost Ordovician is analogous to the sections of Type III. The Silurian begins with marls and aphanitic limestones of the Stačiunai Formation which have yielded few fossils good for correlation.

Type V—sections in east Lithuania and southeast Latvia with an extensive hiatus at the boundary interval. More or less continuous Upper Ordovician deposits are represented by marls and various limestones which end at the top of the Pirgu Regional Stage with the aphanitic limestones of the Taučionys Formation which yield a *Holorhynchus* fauna. There is a hiatus at the level of the Porkuni, Juuru and Raikküla Regional Stages, or in places there occur thin residual tongues and lenses of the Kuldiga, Saldus and Apasčia Formations, which are transgressively overlain by mudstones and marls of the late Llandovery Adavere Regional Stage.

In the westernmost part of Lithuania and in the Kaliningrad District the rocks of the Ordovician–Silurian boundary interval become still more argillaceous and graptolites occur throughout the whole section, with the exception of the uppermost Ordovician which yields a shelly *Hirnantia* fauna. This is a transition to a different type of facies belt which is distributed in north Poland and the southern part of the present Baltic Sea.

Thus analysis of the lithologies and fossils of the various sections shows that by the end of the Ordovician the Baltic basin had experienced a considerable regression which reached its maximum in the second half of the Porkuni. This is indicated both by hiatuses in the sections (Fig. 3) and by the presence of calcareous oolites and early diagenetic (or sedimentary) dolomi-

	REGIONAL STAGE	NORTH ESTONIA	CENTRAL ESTONIA	SOUTH ESTONIA	WEST LATVIA, W. LITHUANIA	EAST LATVIA, EAST LITHUANIA
SILURIAN	RAIKKÜLA G ₃	RAIKKÜLA Fm.	SAARDE Fm.	Staicele Mb. Lemme Mb. Ikla Mb. Kalka Mb. Slitere Mb.	DOBELE Fm.	
	JUURU G ₁₋₂	Hilliste Mb. Karinu Mb. Tammiku Mb. VARBOLA Fm.	TAMSA-LU Fm.	ÕHNE Fm. Rozēni Mb. Rūja Mb.	REMTE Fm. APASČIA Fm.	STĀČIŪNAI Fm.
ORDOVICIAN	PORKUNI F _{II}	ÄRINA Fm.	KABALA Fm.	SALDUS Fm. KULDIGA Fm.	Brācēni Mb. Bītiene Mb. Lādijs Mb. Bernāti Mb.	SALDUS Fm. KULDIGA Fm.
	PIRGU F _{Ic}	ADILA Fm.	ODSTRIKU Fm. HALLIKU Fm.	JONSTORP Fm.	KUILI Fm. PAROVĒJA Fm. JELGAVA Fm.	ADILA Fm. LUKMERĒ Fm. LUDZA Fm. BALTIŅAVA Fm.
	VORMSI F _{Ib}	KÖRGES-SAARE Fm.	TUDULINNA Fm.	FJÄCKA Fm.	MEILUNAI Fm.	SVEDASAI Fm.
						TAUČIONYS Fm.
TYPES OF SECTIONS	I	II	III	IV	V	

Fig. 3 Stratigraphical scheme of the late Ordovician and early Silurian boundary rocks in the East Baltic area.

tes in the Saldus Formation in the axial part of the basin. The character of the transition from the Porkuni to the Juuru Regional Stage and the lithology of the sequences indicate a rapid deepening of the basin, obviously of glacial eustatic origin (Kaljo *et al.*, in press).

Local stratigraphy

Knowledge of the local stratigraphy of rocks near the Ordovician–Silurian boundary has considerably improved in the past few decades. The correlation chart presented in Fig. 3 is based on the decisions of the regional stratigraphical conferences in Vilnius in 1976 and in Tallinn in 1984 (Grigelis 1978). The chart was compiled from material in many publications (see further references in the papers by Männil 1966, Kaljo 1970, Kaljo & Klaaman 1982, Paškevičius 1979, Grigelis 1982, Ulst *et al.* 1982).

Dynamics of the faunas

From the five regional stages from Vormsi to Raikküla which correspond to the Ashgill and lower and middle Llandovery, extremely rich fossil faunas have been collected. The present paper uses the data obtained through the study of eight groups of fossils: stromatoporoids, tabulate corals, brachiopods, trilobites, ostracodes, chitinozoans, conodonts and graptolites. In total 734 species from 313 genera and 105 families have been identified. Table 1, which is based on data by Nestor *et al.* (in press), shows the distribution of species and genera by stages. It shows that the associations of the Porkuni and Juuru Regional Stages are the least diverse; and also that they have almost no common species, whereas about one third of the genera occur in both stages. At the Ordovician–Silurian boundary, besides intensive extinction of the Ordovician fauna, the rate of the appearance of new fauna also rose. In Porkuni times extinction prevailed and Juuru times were characterized by the appearance of new faunas.

Table 1 Numbers of species and genera of eight fossil groups recorded from the Vormsi to Raikküla Regional Stages.

Regional Stage	Vormsi	Pirgu	Porkuni	Juuru	Raikküla
Species, total number	195	252	154	177	221
transitional from the underlying stage, %	43	38	17	4	22
Genera, total number	150	175	125	109	130
transitional from the underlying stage, %	57	69	49	32	57

The dynamics of the fossil groups varied according to their ecology. For example, the shallowing of the basin in the Late Ordovician led to the radiation of the shallow-water stromatoporoids and corals, whereas the graptolites emigrated completely from the East Baltic area at the same time as the general crisis of graptolites noted by Rickards (1978) became apparent. Shallowing was also of great influence on the benthic trilobites and ostracodes, which usually inhabited deeper shelf areas and a remarkable decrease in their diversity took place in Pirgu and Porkuni times. The reverse tendency can be seen during the rapid deepening of the basin at the beginning of Juuru times; however, at that time shallow-water groups, particularly stromatoporoids and corals, were chiefly affected.

Biostratigraphy and correlation

Space does not allow a more detailed analysis here of the diverse biota from the boundary beds, and so only selected lists of species for each stage are presented, those which are most

valuable for correlation (in brackets the index of the formation is shown where the species has been found).

Vormsi Regional Stage

Catenipora wrighti Klaamann (Kr), *Plaesiomys solaris* Buch (Kr), *Kullervo complectens* (Wiman) (Td), *Acanthochitina barbata* Eisenack (Td, Fj, Ml), *Tretaspis seticornis* (Hisinger) (Fj), *Orthograptus quadrimucronatus* (Hall) (Fj), *Climacograptus styloides* Lapworth (Fj), *Hamarodus estonicus* Viira (Fj), *Belodina compressa* (Branson & Mehl) (M1).

The above species enable a clear determination of the position of the Stage at the level of the graptolite *Pleurograptus linearis* Zone.

Pirgu Regional Stage

In the lower part: *Eospirigerina sulevi* (Alichova) (Mo, Jn, Sv), *Foramenella parkis* (Neckaja) (Mo, Jn, Sv, Ad, Uk), *Amorphognathus ordovicicus* Branson & Mehl (Mo, Jl), *Dicellograptus* cf. *complanatus* Lapworth (Mo), *Rectograptus gracilis* (Roemer) (Hl, Jn), *Pandera megalophthalma* (Linnarsson) (Jn), *Tretaspis latilimba* (Linnarsson) (Jn, Jl, Kl).

In the middle part: *Clathrodictyon microundulatum* Nestor (Ad), *Catenipora tapaensis* (Sokolov) (Ad), *Esthonia asterisca* Roemer (Ad, Uk), *Maclurites neritoides* (Eichwald) (Ad), *Belodina compressa* (Branson & Mehl) (Ad).

In the topmost part: *Conochitina taugourdeaui* Eisenack (Kb), *Climacograptus supernus* Elles & Wood (Kb), *Holorhynchus giganteus* Kiaer (Tč).

The graptolites shown above enable a correlation of the stage with the zones of *Dicellograptus complanatus* and *D. anceps*.

Porkuni Regional Stage

Paleofavosites rugosus Sokolov (Är), *Rhabdotetradium frutex* Klaamann (Är), *Streptis undifera* (Schmidt) (Är), *Iliaenus angustifrons depressa* Holm (Är), *Apatochilina falocata* Sarv (Är), *Dalmanella testudinaria* (Dalman) (Kl), *Hirnantia sagittifera* (M'Coy) (Kl), *Eostropheodonta hirnantensis* (M'Coy) (Kl), *Dalmanitina (Mucronaspis) mucronata* (Brongniart) (Kl, Sl), *Brongniartella platynota* (Dalman) (Kl), *Pseudulrichia norvegica* Henningsmoen (Kl), *Conochitina postrobusta* subsp. A (Nölvak, Ms).

The representatives of the *Hirnantia* and *Dalmanitina* communities enable correlation with the Hirnantian Stage at the level of the zones of *Climacograptus extraordinarius* and *Glyptograptus persculptus*.

Juuru Regional Stage

Clathrodictyon boreale Riabinin (Vr, Tm), *Paleofavosites paulus* Sokolov (Vr, Tm, Öh), *Stricklandia lens prima* Williams (Vr, lower pt), *S. lens lens* Williams (Vr, upper pt), *Borealis borealis* (Eichwald) (Tm), *Calymene ansensis* Männil (Vr, Tm), *Acernaspis estonica* Männil (Öh), *Aitilia senecta* Sarv (Vr), *Steusloffina eris* Neckaja (Vr, Tm, Öh), *Ozarkodina ex gr. oldhamensis* (Rexroad) (Öh, lower pt), *Distomodus* cf. *kentuckyensis* Branson & Branson (Öh), *Ancyrochitina laevaensis* Nestor (Öh, lower pt), *Conochitina postrobusta* Nestor (Öh), *Dimorphograptus confertus* (Nicholson) (Öh, upper pt), *Pribylograptus incommodus* Törnquist (Öh, top).

The top of the Juuru Regional Stage is well defined by graptolites, suggesting that this level approximately coincides with the boundary of the *Dimorphograptus confertus* (equivalent to the *Orthograptus vesiculosus*) and *Coronograptus cyphus* Zones (Kaljo *et al.* 1984). The age of the lower limit of the stage can be established by *Stricklandia lens prima* (according to Cocks, 1971, it equates to the level of the *Parakidograptus acuminatus* Zone) and by the listed chitinozoans and conodonts, indicating that there was no substantial regional hiatus at the base of the Silurian in the East Baltic. However, distinct breaks occur at the margins of the basin, particularly to the southeast.

The correlation of the Raikküla Regional Stage is clearly defined by graptolites within the *Coronograptus cyphus* and *Demirastrites convolutus* Zones (Kaljo 1967; Kaljo 1970; Kaljo *et al.* 1984). Detailed correlations in Estonia were considerably improved by the study of chitinozoans (Nestor 1976).

The present data from graptolites and other evidence permit only general correlation of the East Baltic section with the Dob's Linn section, but finds of *Climacograptus supernus* at the top of the Pirgu and *D. confertus* at the top of the Juuru Regional Stage do not contradict the placing of the Ordovician–Silurian boundary (the base of the *P. acuminatus* Zone) at the top of the Porkuni Regional Stage.

Correlation with the Anticosti section is possible by means of chitinozoans and conodonts. In this section (Achab 1981; McCracken & Barnes 1981) Member 5 of the Ellis Bay Formation is characterized by the presence of *Conochitina taugourdeaui*, *C. micracantha* and *C. gamachiana*. J. Nõlvak has found the first two and a form similar to the third species at the top of the Pirgu Regional Stage. At the base of Member 6 in Anticosti *Ozarkodina oldhamensis* appears, and somewhat higher *Distomodus kentuckyensis* and above bioherms *Ancyrochitina spongiosa* are recorded. P. Männik, V. Nestor and V. Viira have found all these species or closely related forms in the lower part of the Juuru Regional Stage. Thus, in the Anticosti section we do not see equivalents of the Porkuni Regional Stage (at least of its upper part) which is characterized by *Conochitina postrobusta* subsp. A.

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